RAINFALL-RUNOFF RELATIONSHIPS STUDY

Rocky Flats Plant Site

Task 5
of the
Zero-Offsite Water-Discharge Study

Prepared for:

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Rocky Flats Plant Site

EXECUTIVE SUMMARY

This report is prepared for one of a number of studies being conducted for, and in the development of, a Zero-Offsite Water-Discharge Plan for Rocky Flats Plant (RFP) in response to Item C.7 of the Agreement in Principle between the Colorado Department of Health (CDH) and the U.S. Department of Energy (DOE)(DOE and State of Colorado, 1989). The CDH/DOE Agreement Item C.7 states "Source Reduction and Zero Discharges Study: Conduct a study of all available methods to eliminate discharges to the environment including surface waters and ground water. This review should include a source reduction review."

This study, attempted to develop a relationship between the storm rainfall and storm runoff at selected locations at the RFP. The relationship attempted is in the form of a simple linear regression which correlates rainfall to runoff.

Based on existing EG&G data related to both rainfall and runoff, plots of rainfall versus runoff were analyzed. The slope of the "best fit" line correlating rainfall as the dependent variable and runoff as the independent variable was determined using linear regression techniques. The coefficient of determination (R^2) is a measure of the "goodness-of-fit" of the linear regression. The value of R^2 indicates the percent of the original uncertainty that has been explained by the linear model. Ideally, R^2 would be unity (1) indicating that the line explains 100 percent of the variability of the data. Values of R^2 greater than 0.6 are assumed for the purpose of this study to represent a relatively good "fit" and a usable representation of the relationship between rainfall and runoff. Based on the inability to achieve an R^2 value of greater than 0.6 (60 percent) for correlations of rainfall to runoff prior to 1991, this study concludes that there are insufficient data currently available to determine a quantitative relationship between rainfall and runoff at the RFP.

It is recommended that additional precipitation, pond, and runoff data for the RFP be obtained. Specifically, information needed in order to develop a rainfall-runoff relationship includes individual storm data specific to each watershed examined; measurements of runoff associated with individual storms; and daily pond volume and transfer information.

The compilation of individual storm data specific to a particular watershed could be achieved through an expanded meteorological data collection network. It is recommended that recording rain gages be installed in each watershed to be examined in order to measure individual storm events. Continuous event based stream-state monitoring data at sites established for Tasks 2 and 3 of the Zero-Offsite Water-Discharge Study should be utilized to compare with meteorological data gathered specific to each watershed. Finally, transducers and dataloggers purchased by the RFP for other Zero-Discharge tasks are available and should be installed in Ponds A-3, A-4, B-3, B-5, and C-2 to record incremental changes in pond volume resulting in more exact measurements of changes in pond storage. With this additional information, an accurate daily water budget for each pond could be developed enabling the calculation of a relationship with less error.

If additional fine tuning of rainfall-runoff relations was then deemed to be necessary, information on soil types, moisture, and imperviousness, as well as vegetative cover type and density, times of concentration, and evaporation rates would need to be gathered.

RAINFALL-RUNOFF RELATIONSHIPS STUDY
Rocky Flats Plant Site

1.0 INTRODUCTION

The Rainfall-Runoff Relationships Study is one of several studies being conducted for, and in the development of, a Zero-Offsite Water-Discharge Plan for Rocky Flats Plant (RFP) in response to Item C.7 of the Agreement in Principle between the Colorado Department of Health (CDH) and the U.S. Department of Energy (DOE) (DOE and State of Colorado, 1989). The CDH/DOE Agreement Item C.7 states " <u>Source Reduction and Zero Discharges Study:</u> Conduct a study of all available methods to eliminate Rocky Flats discharges to the environment including surface waters and ground water. This review should include a source reduction review."

1.1 PURPOSE AND SCOPE OF THE STUDY

The purpose of this study, is to estimate a relationship between rainfall and runoff at selected locations at the RFP (Figure 1). The relationship used in this study is in the form of a simple linear regression relationship between rainfall and runoff. This approach is similar to that used by Hurr (1976) for Woman Creek. The results of this rainfall-runoff relationship study for the various watersheds at the RFP could then be used to judge if complete capture of storm runoff from selected areas of the RFP could be accomplished for a reasonably large design storm.

As part of the original scope for the Zero-Offsite Water-Discharge Study (ASI, 1990a), it was proposed that existing RFP rainfall and runoff data be analyzed to assess if a relationship between these two hydrologic variables was evident at RFP. EG&G Environmental Management, Clean Water Act Division (EM/CWAD) originally agreed to have another consulting firm perform a rainfall-runoff relationships study at the RFP (ASI, 1990b). ASI's originally proposed task involved project tracking and peer review of efforts with respect to rainfall-runoff relationships studies to have been conducted by the other consulting firm. Efforts to have been conducted by ASI included, but were not limited to, project tracking, peer review, and reporting on the effort of the other consulting firm (ASI, 1990c). However, EG&G EM/CWAD informed EG&G Plant Engineering, Civil-Environmental Restoration (PE/CE-ER) that the other consulting firm would not be performing the rainfall-runoff relationships study as originally planned. Therefore, EG&G PE/CE-ER redirected ASI to perform the rainfall-runoff relationships study, and as a result of this redirection, this report was produced.

The Study as redefined by PE/CE-ER, involved monitoring of rainfall and runoff at existing selected locations at the RFP (ASI, 1991a). Rainfall data were obtained from EG&G Rocky Flats, Inc. Clean Air and Environmental Reporting Division (CA/ER) and EM/CWAD. These data were collected at the existing meteorological station located in the West Buffer Zone of the plant (Figure 2).

Rainfall-runoff relationships were to have been conducted using runoff data collected at five existing gaging stations located near the Controlled Area of the RFP (Sites SW022, SW023, SW027, SW093, and SW118 (Figure 2)). These runoff data have been collected as a part of Tasks 2 and 3 (Non-Point Source Assessment and Storm-Sewer Infiltration/Inflow and Exfiltration Study; ASI, 1990d). Data collection at the five sites included obtaining stream-stage data from dataloggers. Due to budgetary constraints, however, stream-stage data since August, 1990 have not been reduced to flow values using site specific rating curves. Therefore, this study was limited to existing available runoff data from EG&G at Ponds A-4, B-5, C-1, and C-2, and from pre-August 1990 data from the existing gaging stations which were reduced to flow values as a result of Tasks 2 and 3 study efforts.

1.2 DESCRIPTION OF RFP DRAINAGE BASINS

Three intermittent streams drain the site and flow is generally from west to east. Rock Creek drains the northwestern corner of the RFP and flows to the northeast in the buffer zone to its off-site confluence with Coal Creek. Woman Creek drains the southern portion of the plant and flows eastward to Standley Lake. North and South Walnut Creeks and an unnamed tributary drain the remainder of the site (Figure 2). The three forks of Walnut Creek join in the buffer zone (approximately 0.7 miles downstream of the eastern edge of the Controlled Area) and flow to Great Western Reservoir approximately one mile east of the confluence of these forks of Walnut Creek.

1.3 SURFACE WATER CONTROL SYSTEM

A series of dams, retention/detention ponds, diversion structures, and ditches have been constructed at the plant to control surface water and limit the potential for release of poor quality water. This section describes the retention/detention ponds used in support of the analyses presented in this study.

A series of the subject retention/detention ponds are located in the drainages of Walnut and Woman Creeks and are designated as the A, B, and C series ponds (Figure 2). Ponds on North Walnut Creek are designated A-1, A-2, A-3, and A-4, from west to east. Ponds A-1 and A-2 are used only for spill control, and North Walnut Creek streamflow is diverted around them through an underground pipe. Pond A-3 receives the North Walnut Creek streamflow and plant runoff from the northern portion of the plant site. Pond A-4 is designed for surface-water control and for additional storage capacity for overflow from Pond A-3. Pond A-4 has been chosen for analysis in this study because it appears to be the least affected by non-precipitation related interference of the ponds in the A series.

Five retention/detention ponds are located in South Walnut Creek and are designated as B-1, B-2, B-3, B-4, and B-5, from west to east. Ponds B-1 and B-2 are reserved for spill control, whereas, Pond B-3 receives effluent from the sanitary treatment plant (STP). Ponds B-4 and B-5 receive surface runoff and occasionally collect discharge from Pond B-3. Pond B-5 receives runoff from the central portion of the plant site and is used for surface water runoff control in addition to collection of overflow from Pond B-4. Pond B-5 was chosen for analysis in this study because it appears to be the least affected by non-precipitation related interference of the ponds in the B series.

The two C series ponds, Ponds C-1 and C-2, are located along Woman Creek, south and east of the plant, respectively. Pond C-1 receives streamflow from Woman Creek. Flow to Pond C-1 is diverted around Pond C-2 into the Woman Creek channel downstream of Pond C-2. Pond C-2 is located south of the Woman Creek channel and receives surface runoff from the South Interceptor Canal along the southern portion of the plant site. Both ponds (Ponds C-1 and C-2) in the C series were analyzed in this study.

2.0 DISCUSSION OF AVAILABLE DATA

The data available for examination and analysis related to this study included periodic pond status information in the form of pond volume and pond transfer volume, on-site precipitation information, stream-stage information, and watershed areas. These data were limited, however, relative to the needs of this study. Ideally, more than 5 to 10 years of data would be used to perform this type of analysis. This volume of data is needed to normalize such things as unusually intense storms, and to examine seasonal relationships.

2.1 DATA GATHERED

2.1.1 Pond Status

Pond status in terms of pond volume has been gathered periodically by EG&G for Ponds A-3, A-4, B-5, and C-2 for the period from January 1, 1988 through June 3, 1991. Outflow data have been gathered by EG&G for Ponds A-3, A-4, B-5, C-1, and C-2 for the period from January 1, 1988 through June 3, 1991. STP effluent flow data have been gathered by EG&G for the period from April 1988 through June 3, 1991.

2.1.2 Precipitation

Daily precipitation data at the RFP were gathered at 15 minute intervals by EG&G at a single meteorological station located in the West Buffer Zone. This information was received by ASI in the form of daily precipitation for the period from January 1986 through June 3, 1991.

2.1.3 Watershed Areas

Watershed areas of Ponds A-4, B-5, C-1, and C-2 (Figure 3), and for monitoring sites SW022, SW023, SW027, SW093 and SW118 were obtained from the Tasks 2 and 3 Interim Report (ASI, 1990d).

2.2 DATA LIMITATIONS

Pond volume, pond transfer volume, and pond outflow (discharge) volume information received by ASI for analyses related to this study were incomplete for the needs of this study. Pond status data was only available periodically for the periods mentioned in Section 2.1.1 (January 1988 to June 1991). Therefore, interpolations of pond status were used to estimate changes in storage in the terminal storage ponds (Ponds A-4, B-5, and C-2).

Records of the quantity and timing of water diversion from one pond to another and from various irrigation ditches were incomplete. These data presented total volumes transferred during various blocks of time ranging between 2 and 90 days, but did not differentiate transfers in daily increments. Therefore, the total volume transferred was assumed to be averaged over the block of time presented. No pond transfer information was produced by EG&G for Pond B-3, which receives discharges from the STP, and sometimes discharges to Pond B-5. These types of diversions will skew the data, resulting in inaccurate runoff volume calculations.

Precipitation data also were limited in their usefulness for this study. Precipitation data were not always available for individual storm events. Additionally, no indication was given in fall, winter, or spring months as to whether the precipitation occurred as snow or as rain. Additional information that would have enabled a more precise determination of a rainfall-runoff relationship includes soil moisture content prior to storm events, average infiltration and evaporations rates for the area, and initial abstractions.

3.0 RAINFALL-RUNOFF ANALYSIS

3.1 APPROACH

An attempt was made to estimate a relationship between rainfall and runoff at selected pond locations and at surface water monitoring sites by using linear regression techniques. The approach used in this study was described by Viessman and others (1977). The procedure involves plotting precipitation versus runoff, finding the slope of the "best fit" line and estimating relationship as the percentage of precipitation appearing as runoff. This procedure was used instead of a more involved method. A more involved analytical method may have produced more accurate results but due to the limited data that was available, and budgetary and time constraints the approach presented by Viessman was used. The runoff quantities determined using this approach are crude and subject to large errors. The degree of reliability is higher for drainage areas whose properties are least subject to seasonal or other types of variations (Viessman and others, 1977). The resulting equation takes the form:

$$Q = sP + P_b$$

where:	Q	=	runoff from precipitation (P)
	s	=	the slope of the line
	P_b	=	a base precipitation value below which Q is zero.

Runoff was assumed to be equal to the inflow at the pond selected for analysis, after attempting to adjust the runoff for outside influences such as pond transfers and STP discharges. These data were analyzed assuming that the inflow into the pond was equal to the change in the pond storage plus the outflow. Both the change in pond storage and the outflow values were based on interpolations of periodic EG&G measurements.

The slope of the "best fit" line was determined using linear regression techniques. Several scenarios were attempted to develop a linear relationship with a coefficient of determination (R^2)

value that indicated a reasonably good fit. R^2 is a measure of the "goodness-of-fit" of the linear regression. The value of R^2 indicates the percent of the original uncertainty that has been explained by the linear model. Ideally, R^2 would be unity (1) indicating that the line explains 100 percent of the variability of the data (Chapra, 1988). Values of R^2 greater than 0.6 are assumed for the purpose of this study to represent a relatively good "fit" and a usable representation of the relationship between rainfall and runoff.

In the first scenario, monthly inflow derived from the monthly change in pond storage plus monthly pond outflow, was plotted against monthly precipitation for Ponds A-4, B-5, C-1, and C-2. In the second scenario, monthly inflow derived from the monthly change in storage plus the next months outflow data, was plotted against monthly precipitation for Ponds A-4, B-5, and C-2. In the third scenario, storm runoff at monitoring sites SW027 and SW118 was plotted against measured precipitation for individual storm events recorded as a result of Tasks 2 and 3 (ASI, 1990b). In the fourth scenario, monthly inflow at Pond C-1, (compiled in Task 14, Surface Water and Groundwater Rights Study; ASI, 1991b) was plotted against corresponding monthly precipitation.

Monthly measured discharge of Walnut Creek at Indiana Street, less monthly outflow at Ponds A-4 and B-5 also was plotted against corresponding monthly precipitation measured at the EG&G meteorological station in an attempt to remove the effects of water diversions from one pond to another. It was hoped that these resultant flow volumes would be representative of actual runoff in Walnut Creek at Indiana Street.

Additionally, an attempt was made to normalize all the runoff data by dividing each calculated inflow value by the respective drainage area of each pond. These normalized inflow data also were plotted against monthly precipitation, and linear regression analyses performed.

When the results of the scenarios described above proved inconclusive, a different approach was undertaken. This method used the same water balance methodology on Ponds A-4, B-5, and C-2 as described above, however, data was interpolated on a daily basis instead of monthly. Inflow into the ponds was calculated for one and two days within precipitation events totaling more than 0.1 inches. It was assumed that any less precipitation in a day would all be absorbed and would not runoff.

3.2 RESULTS

Graphs of the above scenarios were plotted and linear regression analyses performed to determine the relationship between pond inflow or runoff and precipitation (Figures 4 through 9). R^2 values for the analyses conducted as a result of this study are given in Table 1.

Of the comparison results given in Table 1, only comparisons between 2-day inflow and precipitation in Ponds B-5 and C-2 in 1991 resulted in R^2 values greater than 0.6 or 60 percent. This degree of agreement is most likely explained by the fact that Pond B-3, which receives effluent from the STP, only began discharging to Pond B-5 on a daily basis in 1991. Prior to 1991, Pond B-3 releases had been random and release volumes were irregular, skewing the effect of the water balance.

The rainfall-runoff relationship presented in Table 1 and on Figure 5 for 1991 Pond B-5, 2-day inflow versus precipitation indicates that 100 percent of the precipitation above the abase precipitation of 0.05 inches would result in runoff. It is doubtful that 100 percent of the precipitation would result in runoff at such a low base precipitation value. This high runoff coefficient is thought to be the result of STP effluent transfers from Pond B-3 and not the result of precipitation.

The rainfall-runoff relationship presented in Table 1 and on Figure 6 for 1991 Pond C-2, 2-day inflow versus precipitation indicates that 60 percent of the precipitation above the base precipitation of -0.08 inches would result in runoff. Although the -0.08 inches of base

TABLE 1

R^2 VALUES CORRESPONDING TO RAINFALL-RUNOFF RELATIONSHIPS

GRAPH NAME		Equation	R^2
Pond A-4	Monthly Inflow vs. Monthly Precipitation	y=4.7x+15	.126
Pond A-4	Monthly Inflow (Calculated Outflow from the following month) vs. Monthly Precipitation	y=1.7x+7	.049
Pond A-4	Normalized (Monthly Inflow in Acre-Ft/Area of Drainage Basin	y=7.8x+25	.126
1991 Pond A-4	2-Day Inflow vs. Precipitation	y=2.0x-.02	.320
Pond B-5	Monthly Inflow vs. Monthly Precipitation	y=0.25x+4	.015
Pond B-5	Monthly Inflow (Calculated Outflow from the following month) vs. Monthly Precipitation	y=4.5x+2.8	.568
Pond B-5	Normalized (Monthly Inflow in Acre-Ft/Area of Drainage Basin	y=8.8x+6.2	.544
1990 Pond B-5	2-Day Inflow vs. Precipitation	y=0.03x+.8	.000
1991 Pond B-5	2-Day Inflow vs. Precipitation	y=1.0x+.05	.654
Pond C-1	Monthly Discharge vs. Monthly Precipitation	y=.001x+.87	.005
Pond C-1	Monthly Discharge vs. Monthly Precipitation (Normalized)	y=14x+59	.031
Pond C-2	Monthly Inflow vs. Monthly Precipitation	y=0.22x+1.7	.022
Pond C-2	Monthly Inflow (Calculated Outflow from the following month) vs. Monthly Precipitation	y=1.9x+1.3	.269
Pond C-2	Normalized (Monthly Inflow in Acre-Ft/Area of Drainage Basin	y=5.7x+5.1	.255
1991 Pond C-2	2-Day Inflow vs. Precipitation	y=0.6x-.08	.621
SW027	Rainfall vs. Runoff	y=0.25x-0.2	.332
SW118	Rainfall vs. Runoff	y=0.8x-0.1	.144
Walnut	Monthly Discharge at Walnut Creek Less Monthly Outflow at Ponds A-4 and B-5 vs. Monthly Precipitation	y=0.4x+2	.005

precipitation is a physical impossibility, a value of 0.1 inches of base precipitation should probably be used instead, the runoff coefficient of 60 percent appears to be realistic.

4.0 PREVIOUS HYDROLOGIC INVESTIGATIONS

Hurr (1976) developed a rainfall-runoff relation for Woman Creek basin in his 1976 study of the hydrology of the Rocky Plant site. This rainfall-runoff relation was developed by examining the rainfall and streamflow records from 1972 to 1975, and plotting the storm rainfall against the volume of surface runoff attributable to the storm. In this study, Hurr reported that the runoff averages about 1.4 percent of the rainfall, assuming equal rainfall distribution over the entire basin. Hurr concluded that this small volume of storm runoff indicates a high infiltration rate for the soil cover in the basin. He concluded that another factor contributing to the small volume of runoff is that most of the records that were used to develop the relations resulted from frontal storms with long rainfall durations. Hurr stated that rainfall intensity during this type of storm seldom exceeds the potential infiltration rate of the soil; thus, little surface runoff is generated. The percentage of runoff from intense summer thunderstorms would be much greater because of the high rainfall intensities associated with this type of storm. Hurr concluded that because of insufficient data, a quantitative relationship between thunderstorm rainfall and runoff could not be developed (Hurr, 1976).

Preliminary analysis of precipitation and discharge data at several surface monitoring sites was performed for Tasks 2 and 3 Studies (Non-Point Source Assessment and Storm-Sewer Infiltration/Inflow and Exfiltration Studies (ASI, 1990a). The daily mean discharges presented in the Tasks 2 and 3 studies appear to be in response to storms whose intensity and duration are reflected by the daily precipitation data collected at the EG&G meteorological station located in the West Buffer Zone, approximately 1.7 miles from the nearest flow-gaging site, Site SW118, and 2.8 miles from the furthest flow-gaging site, Site SW027 (Figure 2). The preliminary analysis of these precipitation and discharge data related to the period May 1990 through August 1990, indicated that the largest storm for which runoff was measured occurred during July 4 through 11, 1990, and had a total precipitation of 1.62 inches. The storm runoff during July 4-11, 1990 was estimated to be about 0.25 inches (or approximately 15 percent of the recorded rainfall) at Site SW027 and about 1.0 inches (approximately 62 percent of the recorded rainfall) at Site SW118. The second largest storm measured at the meteorological station during these two months of the summer of 1990 was 1.37 inches of precipitation during July 19 through 23, 1990. Runoff resulting from this storm was estimated to be about 0.34 inches (or approximately 25 percent of the recorded storm rainfall) at Site SW027 and about 2.0 inches (or approximately 146 percent of the recorded storm rainfall) at Site SW118. It was concluded that this uneven runoff response to a point precipitation amount is typical of the semi-arid environment, the nature of high-intensity localized convective storms typical of the Denver metropolitan area, and the distance of analyzed runoff from the precipitation measuring point (ASI, 1990a).

Also noted in the Task 2 and 3 study was that for certain periods of no observed precipitation at the EG&G meteorological station during the month of September 1990, several monitoring sites recorded flow events which substantially exceeded the expected non-rainfall flow quantities. The sources of water which caused these flows are unknown but could have been from upstream releases, surface washing, or fire hydrant tests which release water to the environment.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made as a result of the preliminary analyses of the available data for the confirmation of rainfall-runoff relationships study:

5.1 CONCLUSIONS

Based on the inability to achieve an R^2 value of greater than 60 percent for any of the comparisons of rainfall to runoff prior to 1991 at the locations examined, it is concluded that there is insufficient data currently available to determine a quantitative relationship with any confidence. This finding is supported by Hurr's conclusion in 1976 that individual thunderstorm data are required in order to develop quantitative relationships of rainfall and runoff.

5.2 RECOMMENDATIONS

Determination of the rainfall-runoff relationships at the RFP is extremely important in the effort to determine if zero-offsite water-discharge is achievable. Therefore, an attempt should be made to gather both sufficient quantity and quality of data to make this determination possible. It is recommended that additional precipitation and runoff data for the RFP be obtained. Specifically, information needed in order to determine a rainfall-runoff relationship includes individual storm data specific to each watershed examined, measurements of runoff associated with the individual storms, soil moisture content prior to the individual storm events, watershed boundaries and areas, soil types and imperviousness, vegetative cover type and density, and times of concentration (ASI, 1990a).

The recording rain gage located in the West Buffer Zone of the RFP may not be representative of rainfall at other locations of the RFP site. Measured storm runoff at several different locations in the RFP site for a single storm rainfall indicated that the runoff may exceed the measured storm rainfall at the existing rain gage location. Therefore, additional recording or bulk rain gages should be installed on selected watersheds on the RFP. In this way, areal and temporal variations in the rainfall patterns at the RFP could be analyzed. This is especially important for high-intensity convective storms typical of the RFP area during the late spring and summer (ASI, 1990d). Information on individual precipitation events obtained from these rain gages could then be compared to flow data for the specific precipitation event obtained from the existing monitoring sites.

More thorough records on inflow, outflow, water diversion and other external effects at selected ponds should be kept. Specifically, transducers and dataloggers could be installed in Ponds A-3, A-4, B-3, B-5, and C-2 to record incremental changes in pond volume resulting in continuous and more accurate measurements of changes in pond storage. Additionally, daily records on pond transfer and discharge volumes should be kept in order to be able to develop an accurate daily water budget for each pond and to more precisely measure the effects of individual precipitation events.

Field confirmation of soil types, imperviousness, vegetative cover type, vegetative density, and other run-off factors should also be performed periodically to provide greater confidence to the rainfall-runoff relationships.

6.0 ACKNOWLEDGEMENTS

This study was conducted under the general supervision of Mr. Michael G. Waltermire, P.E., Project Manager, Advanced Sciences, Inc. (ASI). Work involving this project task was under the technical management of Dr. James R. Kunkel, P.E., P.H., ASI Principal Scientist. Data evaluation was performed by Ms. Dawn A. Tschanz, ASI Engineer, and Ms. Laurie A. Host, ASI Hydrogeologist. This report was written by Ms. Laurie Host, with assistance from Dr. Kunkel and Mr. Waltermire. The draft of this report was reviewed by Mike Rengel, P.E., ASI Project Director. EG&G responsive reviewers of this report included: R.A. Applehans, Project Engineer.

This study report has been prepared and submitted in partial fulfillment of the Zero-Offsite Water-Discharge Study being conducted by ASI on behalf of EG&G Rocky Flats, Inc. EG&G's Project Engineer for this study was Mr. R. A. Applehans of EG&G's Plant Engineering/Civil Engineering - Environmental Restoration Division (PE/CE-ER).

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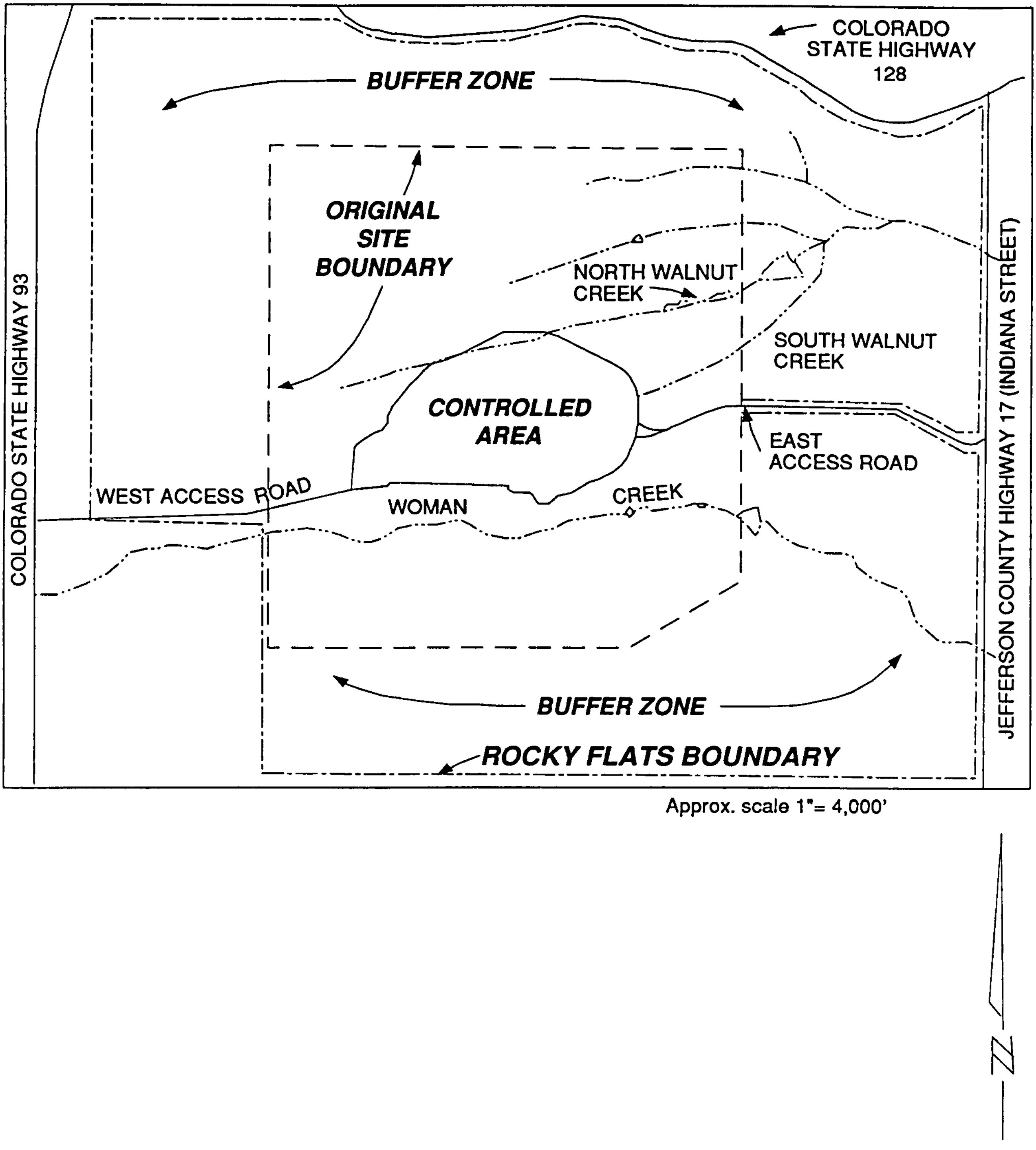
FIGURES

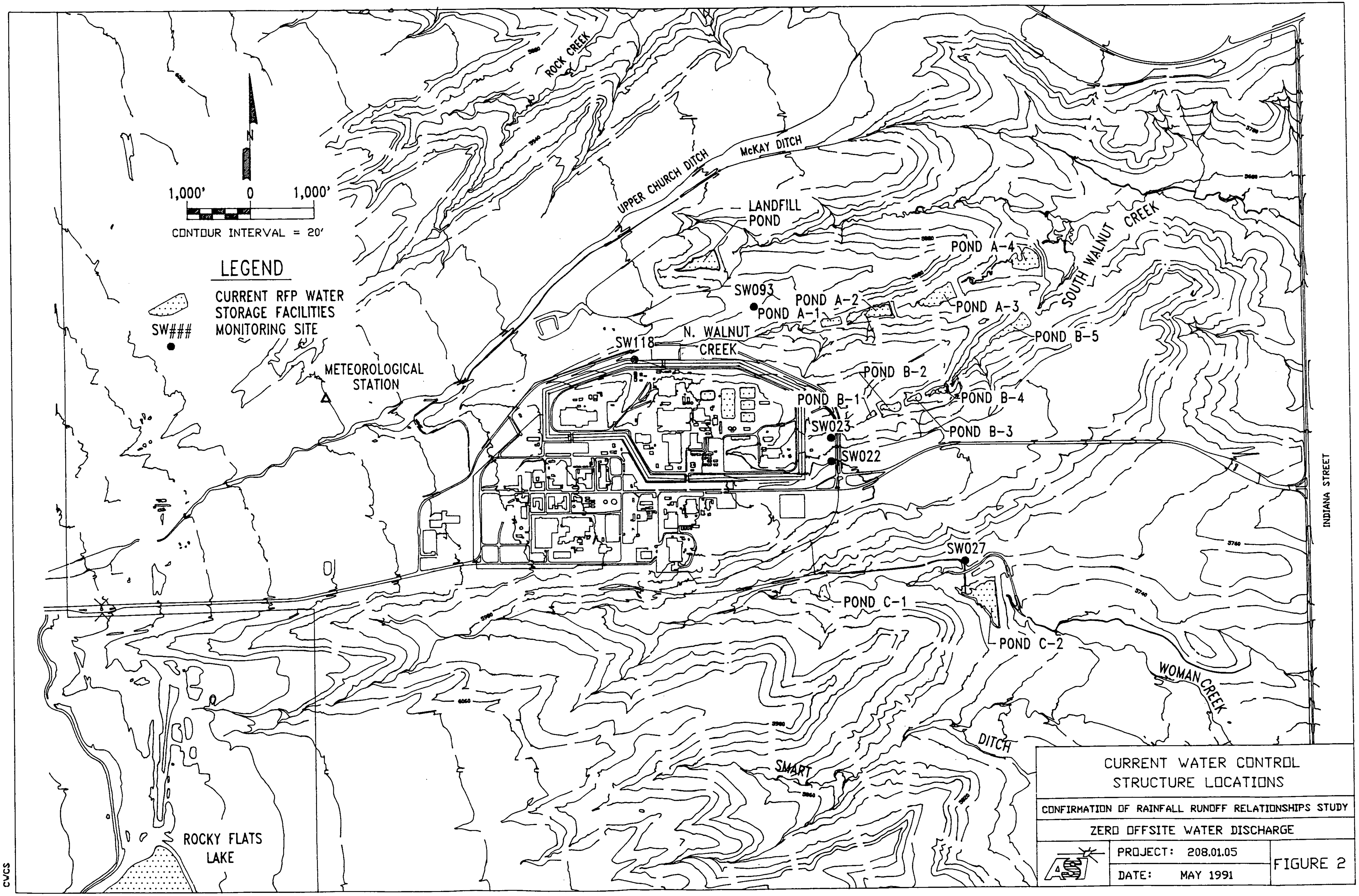


LOCATION MAP

CONFIRMATION OF RAINFALL/RUNOFF RELATIONSHIPS STUDY
ZERO-OFFSITE WATER-DISCHARGE

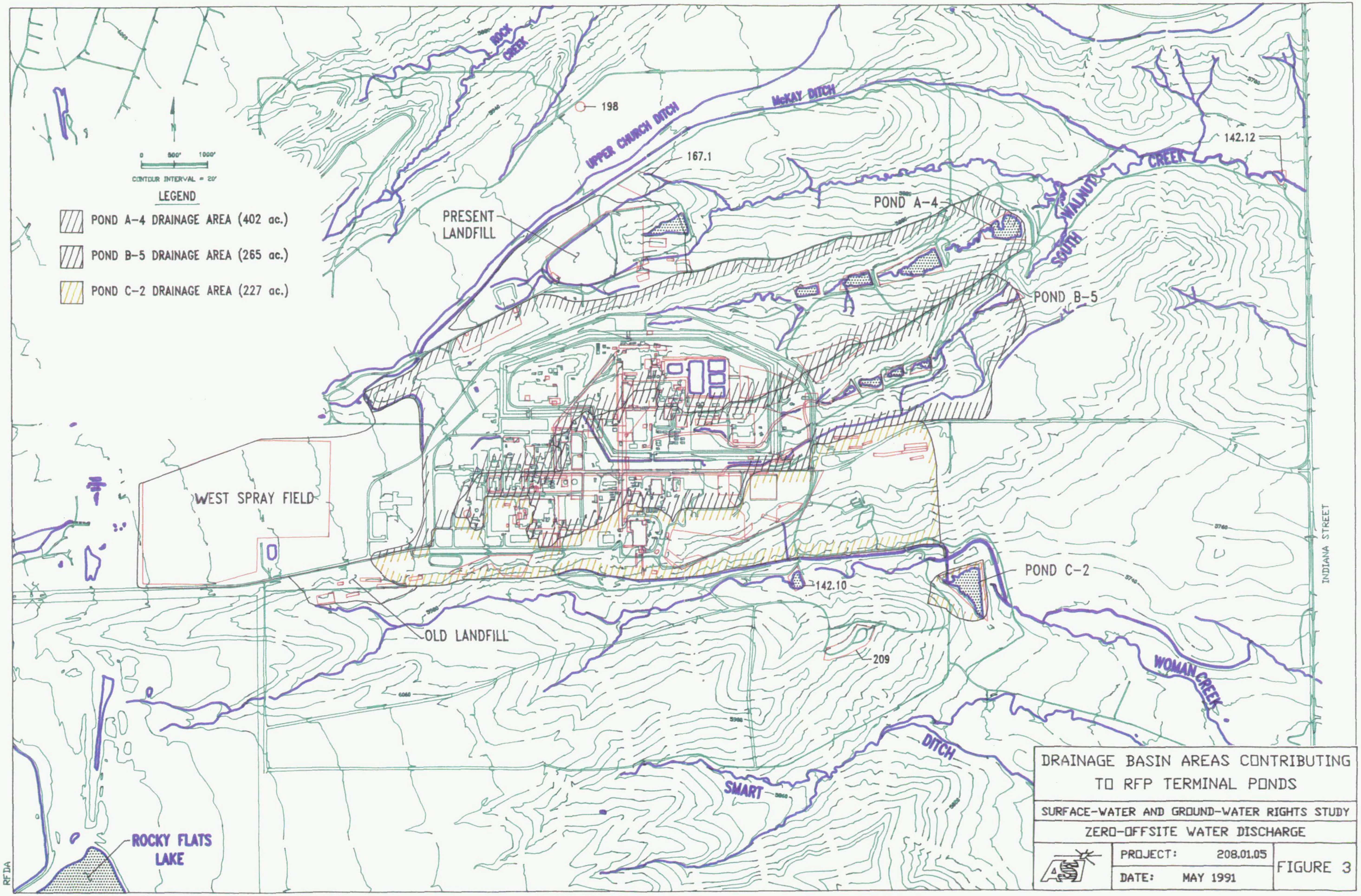
Project No. 208.01.05

Figure 1



CURRENT WATER CONTROL STRUCTURE LOCATIONS	
CONFIRMATION OF RAINFALL RUNOFF RELATIONSHIPS STUDY	
ZERO OFFSITE WATER DISCHARGE	
PROJECT: 208.01.05	FIGURE 2
DATE: MAY 1991	

CVCS



DRAINAGE BASIN AREAS CONTRIBUTING TO RFP TERMINAL PONDS

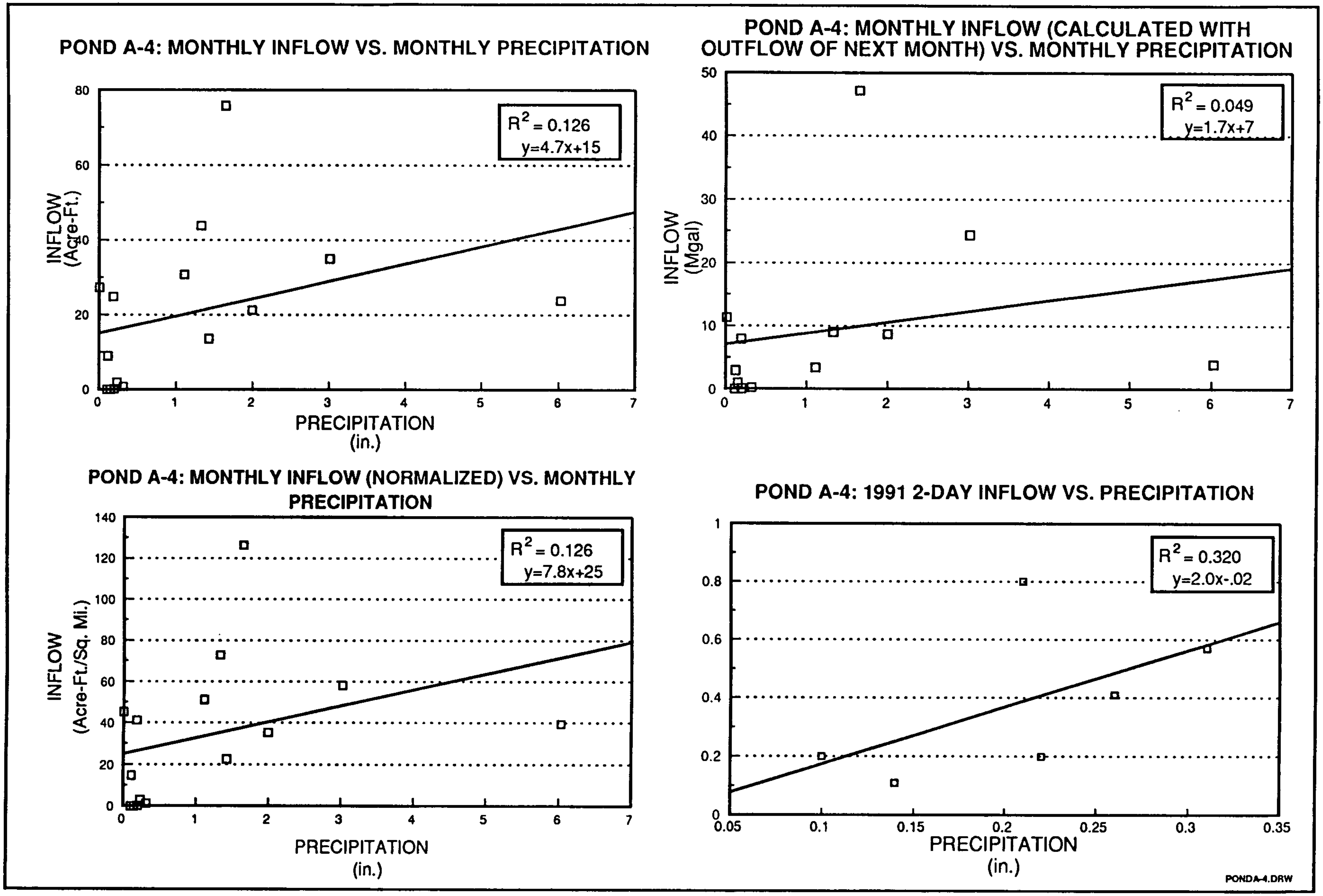
SURFACE-WATER AND GROUND-WATER RIGHTS STUDY

ZERO-OFFSITE WATER DISCHARGE

PROJECT: 208.01.05

DATE: MAY 1991

FIGURE 3

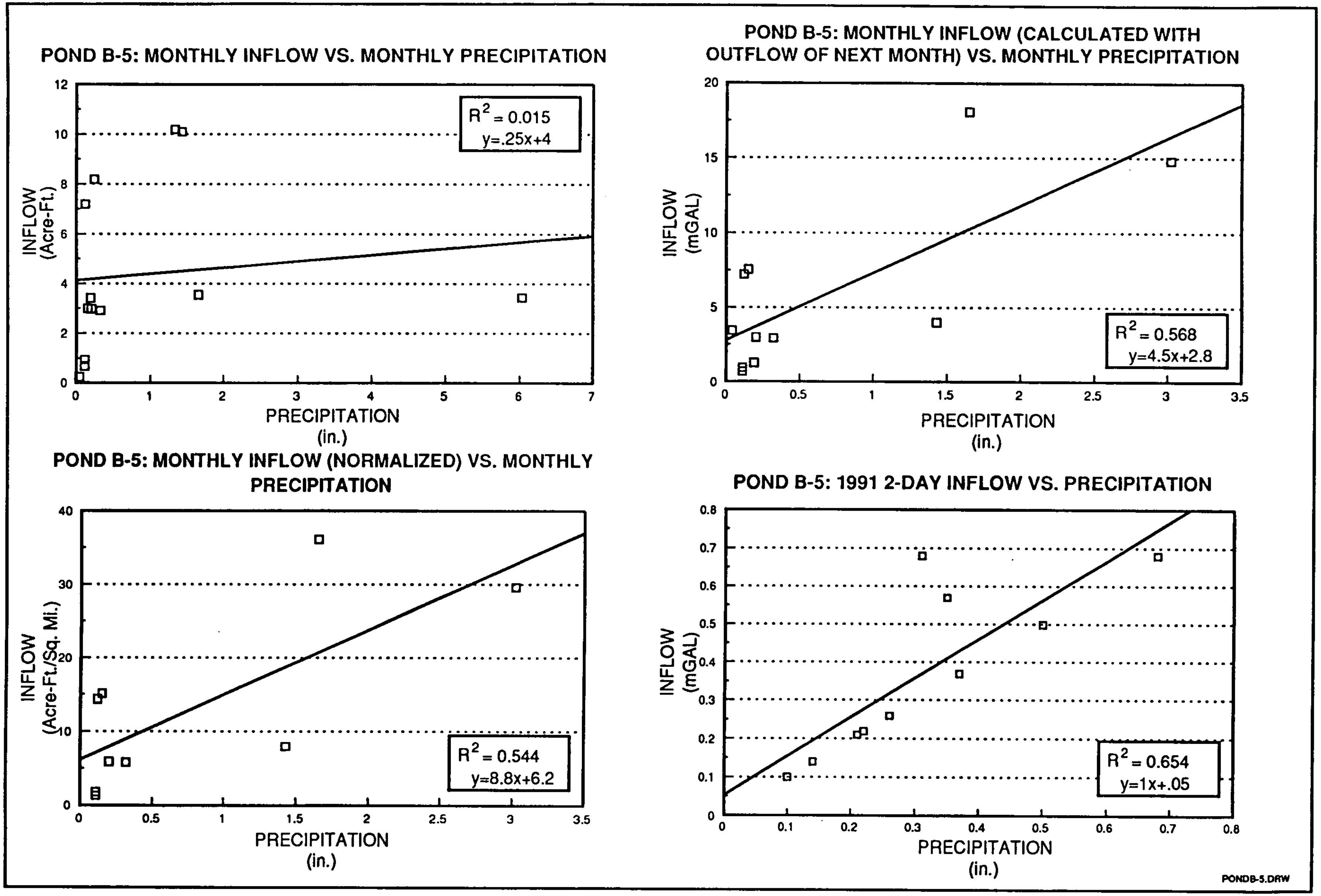


RAINFALL VS. RUNOFF GRAPHS - POND A-4

CONFIRMATION OF RAINFALL/RUNOFF RELATIONSHIPS STUDY
ZERO OFFSITE WATER DISCHARGE STUDY

Project No. 208.01.05

Figure 4

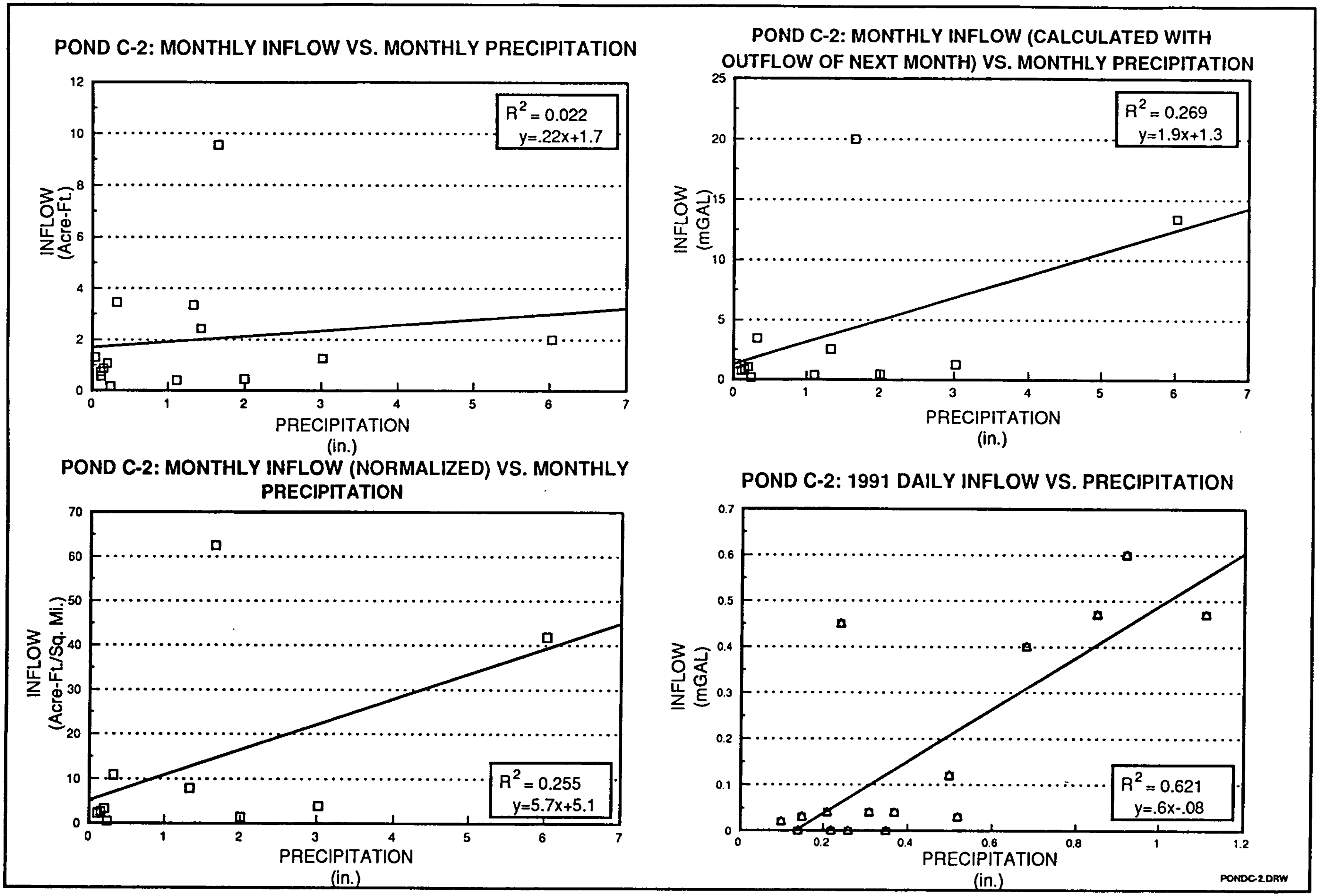


RAINFALL VS. RUNOFF GRAPHS - POND B-5

CONFIRMATION OF RAINFALL/RUNOFF RELATIONSHIPS STUDY
ZERO OFFSITE WATER DISCHARGE

Project No. 208.01.05

FIGURE 5

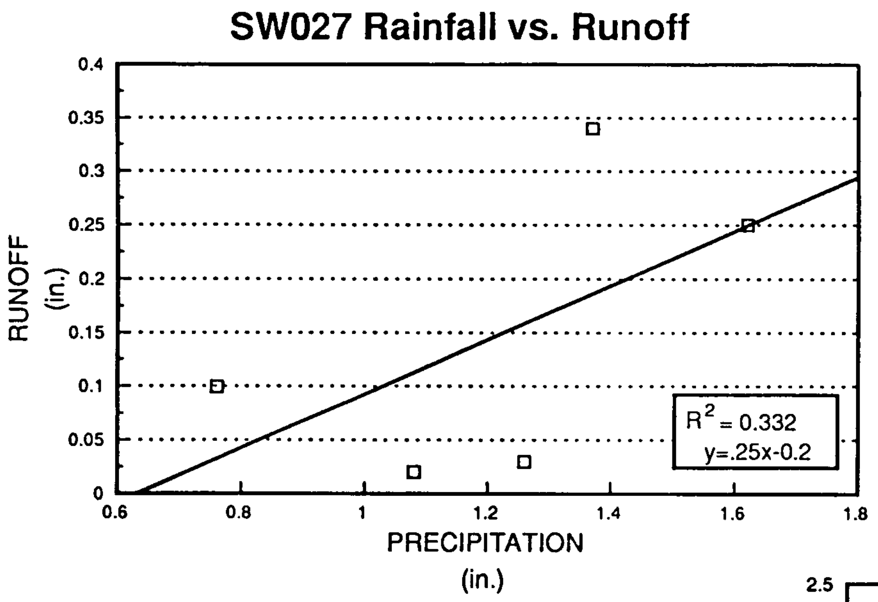


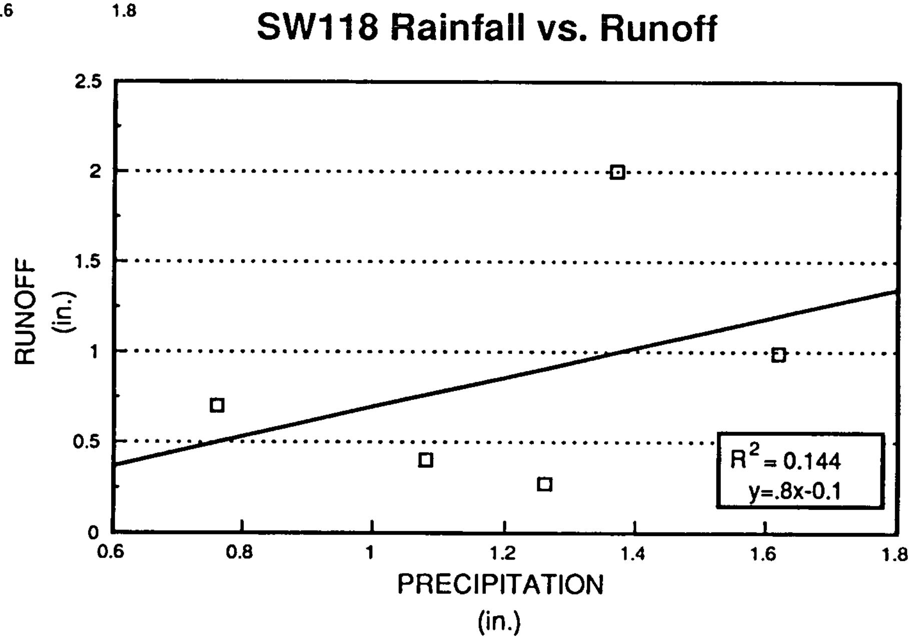
RAINFALL VS. RUNOFF GRAPHS - POND C-2

CONFIRMATION OF RAINFALL/RUNOFF RELATIONSHIPS STUDY
ZERO OFFSITE WATER DISCHARGE

Project No. 208.01.05

Figure 6





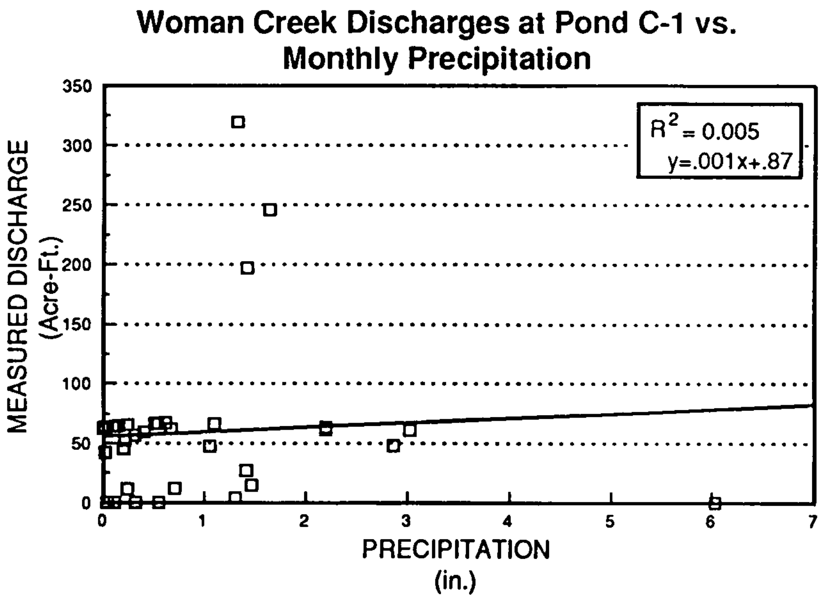
SW27&118.DRW

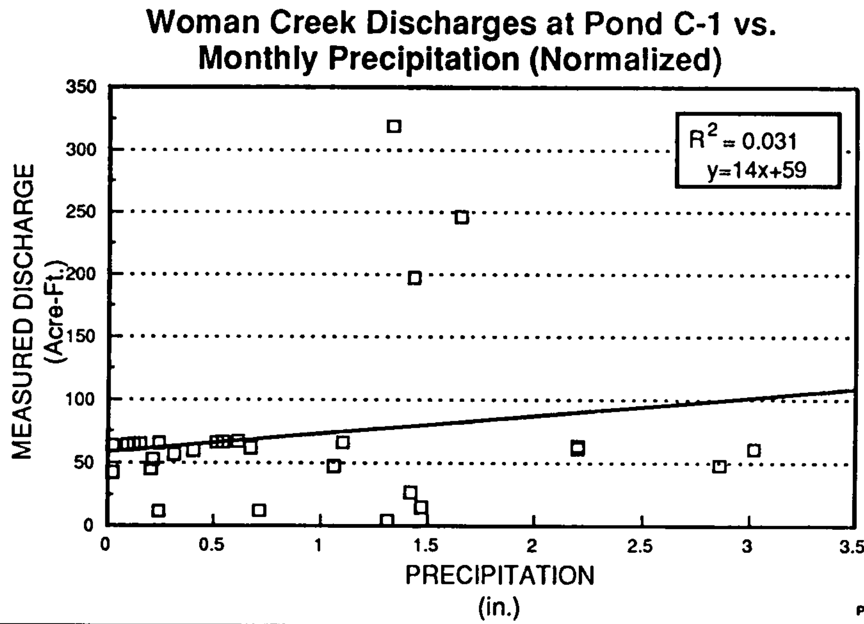
RAINFALL VS. RUNOFF GRAPHS - SW027 AND SW118

CONFIRMATION OF RAINFALL/RUNOFF RELATIONSHIPS STUDY
ZERO OFFSITE WATER DISCHARGE

Project No. 208.01.05

Figure 7





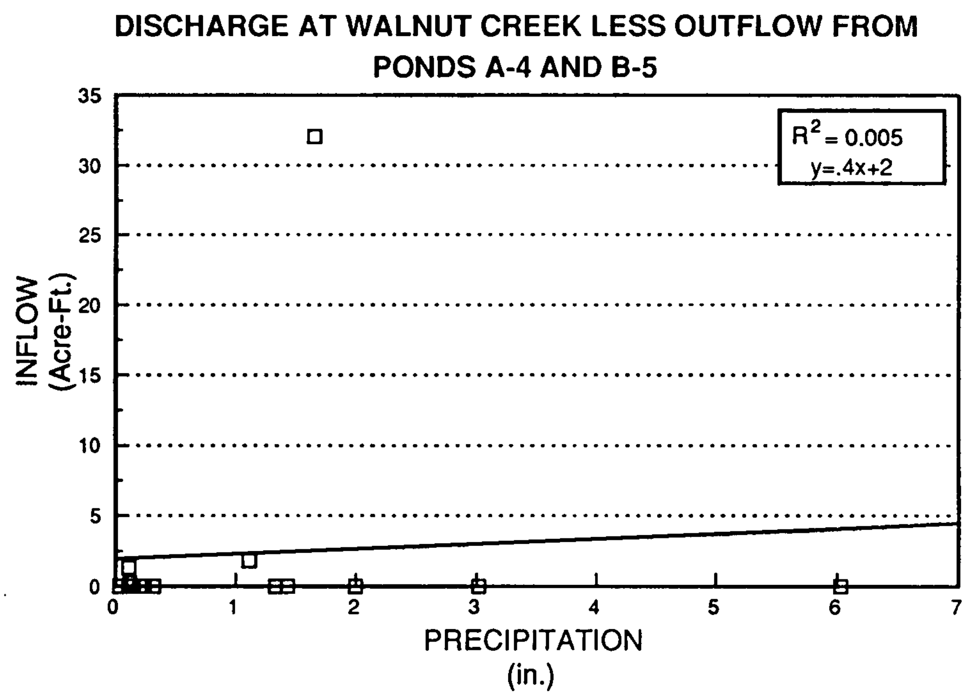
PONDC-1.DRW

RAINFALL VS. RUNOFF GRAPHS - POND C-1

CONFIRMATION OF RAINFALL/RUNOFF RELATIONSHIPS STUDY
ZERO OFFSITE WATER DISCHARGE

Project No. 208.01.05

Figure 8



RAINFALL VS. RUNOFF GRAPHS - WALNUT CREEK LESS OUTLFOW FROM PONDS A-4 AND B-5

CONFIRMATION OF RAINFALL/RUNOFF RELATIONSHIPS STUDY
ZERO OFFSITE WATER DISCHARGE

Project No. 208.01.05

Figure 9

A

APPENDIX A

MONTHLY INFLOW VS. MONTHLY PRECIPITATION

POND A-4: MONTHLY INFLOW VS. MONTHLY PRECIPITATION

MONTH	INFLOW (Ac.-Ft.)	PRECIP. (In.)
10/01/89	23.831	6.03
12/01/89	0.000	0.11
01/01/90	0.815	0.32
02/01/90	0.105	0.20
03/01/90	0.000	0.15
04/01/90	75.876	1.65
05/01/90	43.786	1.33
06/01/90	13.587	1.43
07/01/90	8.898	0.12
08/01/90	34.980	3.02
09/01/90	1.884	0.24
10/01/90	21.284	2.00
11/01/90	30.788	1.11
01/01/91	27.248	0.01
02/01/91	24.793	0.19

Regression Output:

Constant		14.97209
Std Err of Y Est		20.36375
R Squared		0.126672
No. of Observations		15
Degrees of Freedom		13
X Coefficient(s)	4.650776	
Std Err of Coef.	3.386893	

Notes: Dates of negative inflow have been deleted.
Dates with missing data have been deleted.

POND A-4: MONTHLY INFLOW (CALCULATED WITH OUTFLOW OF NEXT MONTH) VS. MONTHLY PRECIPITATION

MONTH	INFLOW (Mgal.)	PRECIP. (In.)
10/01/89	3.90	6.03
12/01/89	0.00	0.11
01/01/90	0.27	0.32
02/01/90	0.03	0.20
03/01/90	0.93	0.15
04/01/90	47.17	1.65
05/01/90	9.03	1.33
07/01/90	2.90	0.12
08/01/90	24.41	3.02
10/01/90	8.68	2.00
11/01/90	3.35	1.11
01/01/91	11.35	0.01
02/01/91	7.94	0.19

Regression Output:

Constant		7.077089
Std Err of Y Est		13.46506
R Squared		0.049649
No. of Observations		13
Degrees of Freedom		11
X Coefficient(s)	1.721821	
Std Err of Coef.	2.271314	

Notes: Dates of negative inflow have been deleted.
Dates with missing data have been deleted.

POND A-4: MONTHLY INFLOW (NORMALIZED) VS. MONTHLY PRECIPITATION

MONTH	INFLOW (AcF/MiSq)	PRECIP. (In.)
10/01/89	39.72	6.03
12/01/89	0.00	0.11
01/01/90	1.36	0.32
02/01/90	0.18	0.20
03/01/90	0.00	0.15
04/01/90	126.46	1.65
05/01/90	72.98	1.33
06/01/90	22.64	1.43
07/01/90	14.83	0.12
08/01/90	58.30	3.02
09/01/90	3.14	0.24
10/01/90	35.47	2.00
11/01/90	51.31	1.11
01/01/91	45.41	0.01
02/01/91	41.32	0.19

Regression Output:

Constant		24.95349
Std Err of Y Est		33.93959
R Squared		0.126672
No. of Observations		15
Degrees of Freedom		13
X Coefficient(s)	7.751293	
Std Err of Coef.	5.644822	

Notes: Dates of negative inflow have been deleted.
Dates with missing data have been deleted.

POND B-5: MONTHLY INFLOW VS. MONTHLY PRECIPITATION

MONTH	INFLOW (Mgal.)	PRECIP. (In.)
09/01/89	0.24	0.04
10/01/89	3.45	6.03
11/01/89	0.93	0.11
12/01/89	0.68	0.11
01/01/90	2.92	0.32
02/01/90	2.98	0.20
03/01/90	3.00	0.15
04/01/90	3.55	1.65
05/01/90	10.19	1.33
06/01/90	10.10	1.43
07/01/90	7.20	0.12
09/01/90	8.19	0.24
02/01/91	3.42	0.19

Regression Output:

Constant		4.139059
Std Err of Y Est		3.542854
R Squared		0.014868
No. of Observations		13
Degrees of Freedom		11
X Coefficient(s)	0.254129	
Std Err of Coef.	0.623704	

Notes: Dates of negative inflow have been deleted.
Dates with missing data have been deleted.

POND B-5: MONTHLY INFLOW (CALCULATED WITH OUTFLOW OF NEXT MONTH) VS. MONTHLY PRECIPITATION

MONTH	INFLOW (Mgal.)	PRECIP. (In.)
09/01/89	3.45	0.04
11/01/89	0.93	0.11
12/01/89	0.68	0.11
01/01/90	2.92	0.32
02/01/90	2.98	0.20
03/01/90	7.55	0.15
04/01/90	18.09	1.65
06/01/90	4.00	1.43
07/01/90	7.20	0.12
08/01/90	14.84	3.02
02/01/91	1.28	0.19

Regression Output:

Constant		2.787697
Std Err of Y Est		3.996440
R Squared		0.568479
No. of Observations		11
Degrees of Freedom		9
X Coefficient(s)	4.529199	
Std Err of Coef.	1.315357	

Notes: Dates of negative inflow have been deleted.
Dates with missing data have been deleted.

POND B-5: MONTHLY INFLOW (NORMALIZED) VS. MONTHLY PRECIPITATION

MONTH	INFLOW (AcF/MiSq)	PRECIP. (In.)
11/01/89	1.85	0.11
12/01/89	1.35	0.11
01/01/90	5.85	0.32
02/01/90	5.95	0.20
03/01/90	15.11	0.15
04/01/90	36.17	1.65
06/01/90	8.00	1.43
07/01/90	14.40	0.12
08/01/90	29.67	3.02

Regression Output:

Constant		6.191677
Std Err of Y Est		8.860014
R Squared		0.544752
No. of Observations		9
Degrees of Freedom		7
X Coefficient(s)	8.808565	
Std Err of Coef.	3.043546	

Notes: Dates of negative inflow have been deleted.
Dates with missing data have been deleted.

POND C-2: MONTHLY INFLOW VS. MONTHLY PRECIPITATION

MONTH	INFLOW (Mgal)	PRECIP. (In.)
09/01/89	1.30	0.04
10/01/89	2.00	6.03
12/01/89	0.73	0.11
01/01/90	3.45	0.32
02/01/90	1.05	0.20
03/01/90	0.86	0.15
04/01/90	9.54	1.65
05/01/90	3.33	1.33
06/01/90	2.43	1.43
07/01/90	0.56	0.12
08/01/90	1.25	3.02
09/01/90	0.15	0.24
10/01/90	0.45	2.00
11/01/90	0.39	1.11

Regression Output:

Constant		1.686576
Std Err of Y Est		2.494167
R Squared		0.021878
No. of Observations		14
Degrees of Freedom		12
X Coefficient(s)	0.218431	
Std Err of Coef.	0.421616	

Notes: Dates of negative inflow have been deleted.
Dates with missing data have been deleted.

POND C-2: MONTHLY INFLOW (CALCULATED WITH OUTFLOW OF NEXT MONTH) VS. MONTHLY PRECIPITATION

MONTH	INFLOW (Mgal.)	PRECIP. (In.)
09/01/89	1.30	0.04
10/01/89	13.39	6.03
12/01/89	0.73	0.11
01/01/90	3.45	0.32
02/01/90	1.05	0.20
03/01/90	0.86	0.15
04/01/90	19.97	1.65
05/01/90	2.53	1.33
08/01/90	1.25	3.02
09/01/90	0.15	0.24
10/01/90	0.45	2.00
11/01/90	0.39	1.11

Regression Output:

Constant		1.285850
Std Err of Y Est		5.605290
R Squared		0.269333
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	1.857384	
Std Err of Coef.	0.967422	

Notes: Dates of negative inflow have been deleted.
Dates with missing data have been deleted.

POND C-2: MONTHLY INFLOW (NORMALIZED) VS. MONTHLY PRECIPITATION

MONTH	INFLOW (AcF/MiSq)	PRECIP. (In.)
10/01/89	41.86	6.03
12/01/89	2.27	0.11
01/01/90	10.79	0.32
02/01/90	3.27	0.20
03/01/90	2.68	0.15
04/01/90	62.42	1.65
05/01/90	7.90	1.33
08/01/90	3.91	3.02
09/01/90	0.47	0.24
10/01/90	1.41	2.00

Regression Output:

Constant		5.148213
Std Err of Y Est		19.27922
R Squared		0.255057
No. of Observations		10
Degrees of Freedom		8
X Coefficient(s)	5.679949	
Std Err of Coef.	3.431954	

Notes: Dates of negative inflow have been deleted.
Dates with missing data have been deleted.

Woman Creek Discharges at Pond C-1 vs. Monthly Precipitation
(Q data from 208.0114 Report)

Month	Q (Ac-Ft)	Precip. (in.)
10/31/87	47.5	1.06
11/30/87	66.1	1.10
12/31/87	66.9	0.61
01/31/88	56.7	0.31
02/29/88	65.4	0.24
03/31/88	61.9	0.67
04/30/88	62.3	0.00
05/31/88	48.0	2.86
06/30/88	12.1	0.71
07/31/88	14.9	1.47
08/31/88	4.0	1.31
09/30/88	26.8	1.42
10/31/88	63.8	0.09
11/30/88	59.4	0.40
12/31/88	66.6	0.54
01/31/89	52.4	0.21
02/28/89	66.3	0.51
03/31/89	63.5	2.20
04/30/89	63.5	0.02
05/31/89	61.3	2.20
06/30/89	42.1	0.02
07/31/89	0.0	0.55
08/31/89	0.0	0.04
09/30/89	0.0	6.03
10/31/89	0.0	0.11
11/30/89	0.0	0.11
12/31/89	0.0	0.32
01/31/90	45.2	0.20
02/28/90	64.7	0.15
03/31/90	246.0	1.65
04/30/90	319.0	1.33
05/31/90	197.0	1.43
06/30/90	64.2	0.12
07/31/90	61.0	3.02
08/31/90	11.6	0.24

Regression Output:

Constant		0.878364
Std Err of Y Est		1.219804
R Squared		0.004539
No. of Observations		35
Degrees of Freedom		33
X Coefficient(s)	0.001205	
Std Err of Coef.	0.003106	

Pond C-1 Data with months of zero discharge and zero precipitation deleted

Month	Q (Ac-Ft)	Precip. (in.)
10/31/87	47.5	1.06
11/30/87	66.1	1.10
12/31/87	66.9	0.61
01/31/88	56.7	0.31
02/29/88	65.4	0.24
03/31/88	61.9	0.67
05/31/88	48.0	2.86
06/30/88	12.1	0.71
07/31/88	14.9	1.47
08/31/88	4.0	1.31
09/30/88	26.8	1.42
10/31/88	63.8	0.09
11/30/88	59.4	0.40
12/31/88	66.6	0.54
01/31/89	52.4	0.21
02/28/89	66.3	0.51
03/31/89	63.5	2.20
04/30/89	63.5	0.02
05/31/89	61.3	2.20
06/30/89	42.1	0.02
01/31/90	45.2	0.20
02/28/90	64.7	0.15
03/31/90	246.0	1.65
04/30/90	319.0	1.33
05/31/90	197.0	1.43
06/30/90	64.2	0.12
07/31/90	61.0	3.02
08/31/90	11.6	0.24

Regression Output:

Constant		58.81739
Std Err of Y Est		69.18819
R Squared		0.031184
No. of Observations		28
Degrees of Freedom		26
X Coefficient(s)	14.22050	
Std Err of Coef.	15.54456	

SW027 and SW118 Rainfall vs. Runoff

Storm Date(s)	Precip. (in.)	SW027 (in.)	SW118 (in.)
7/4-11	1.62	0.25	0.99
7/19-23	1.37	0.34	2
8/11-17	1.26	0.03	0.27
8/30-9/2	1.08	0.02	0.4
9/17-21	0.76	0.1	0.7

SW027
Regression Output:

Constant		-0.159608
Std Err of Y Est		0.133407
R Squared		0.331593
No. of Observations		5
Degrees of Freedom		3
X Coefficient(s)	0.252552	
Std Err of Coef.	0.207018	

SW118
Regression Output:

Constant		-0.117932
Std Err of Y Est		0.736378
R Squared		0.144297
No. of Observations		5
Degrees of Freedom		3
X Coefficient(s)	0.812752	
Std Err of Coef.	1.142695	

DISCHARGE AT WALNUT CREEK LESS OUTFLOW AT PONDS A-4 AND B-5 A-4 AND B-5 VS. MONTHLY PRECIPITATION

MONTH	INFLOW (Ac.-Ft.)	PRECIP. (In.)
09/01/89	0.001	0.04
10/01/89	0.001	6.03
11/01/89	1.310	0.11
12/01/89	0.001	0.11
01/01/90	0.001	0.32
02/01/90	0.001	0.20
03/01/90	0.001	0.15
04/01/90	32.040	1.65
05/01/90	0.001	1.33
06/01/90	0.001	1.43
07/01/90	0.210	0.12
08/01/90	0.000	3.02
09/01/90	0.001	0.24
10/01/90	0.001	2.00
11/01/90	1.800	1.11

Regression Output:

Constant		1.933226
Std Err of Y Est		8.519414
R Squared		0.004865
No. of Observations		15
Degrees of Freedom		13
X Coefficient(s)	0.356758	
Std Err of Coef.	1.415054	

POND B-5: 1990 2-DAY INFLOW VS. PRECIPITATION

DATE	CALC. 2-DAY INFLOW (Mgal)	PRECIP. (in.)
01/19/90	0.26	0.15
02/02/90	0.00	0.10
03/05/90	0.82	0.18
03/06/90	1.40	0.89
03/13/90	0.60	0.45
03/14/90	0.60	0.43
03/27/90	1.53	0.21
03/29/90	1.11	0.15
04/05/90	0.89	0.33
04/09/90	1.81	0.13
05/11/90	0.60	0.13
05/16/90	0.96	0.14
05/28/90	0.00	0.14
05/29/90	2.30	0.48
05/30/90	2.80	0.18
06/19/90	0.47	0.12
07/04/90	0.34	0.60
07/21/90	1.02	0.43
07/23/90	1.36	0.10
07/30/90	0.23	0.12
09/01/90	0.32	0.88
09/02/90	0.40	0.14
09/18/90	0.10	0.61
10/07/90	0.31	0.13
11/06/90	0.31	0.25

Regression Output:

Constant		0.813
Std Err of Y Est		0.733
R Squared		0.000
No. of Observations		25.000
Degrees of Freedom		23.000
X Coefficient(s)	0.028	
Std Err of Coef.	0.630	

Notes: Dates of negative inflow have been deleted.
Dates with missing data have been deleted.

POND A-4: 1991 2-DAY INFLOW VS. PRECIPITATION

Daily Inflow (Mgal.)	2 Day Inflow (Mgal.)	Precip. (In.)
0.00	0.11	0.14
0.11	0.41	0.26
-0.08	0.20	0.10
0.49	0.20	0.22
-0.00	0.80	0.21
0.20	0.57	0.31
-0.00		
0.00		
0.20		
0.32		
0.48		
0.57		
0.00		

Regression Output:

Constant	-0.022
Std Err of Y Est	0.245
R Squared	0.320
No. of Observations	6.000
Degrees of Freedom	4.000
X Coefficient(s)	1.960
Std Err of Coef.	1.428

Notes: Dates of negative inflow have been deleted.
Dates with missing data have been deleted or interpolated.

Pond B-5: 1991 2-Day Inflow vs. Precipitation

2-Day Calculated Inflow (Mgal.)	Precip. (In.)
0.140	0.14
0.260	0.26
0.100	0.10
0.570	0.35
0.220	0.22
0.210	0.21
0.680	0.31
0.370	0.37
0.500	0.50
0.680	0.68

Regression Output:

Constant		0.052
Std Err of Y Est		0.137
R Squared		0.654
No. of Observations		10.000
Degrees of Freedom		8.000
X Coefficient(s)	1.024	
Std Err of Coef.	0.263	

Notes: Dates of negative inflow have been deleted.
Dates with missing data have been deleted or interpolated.

POND C-2: 1991 DAILY INFLOW VS. PRECIPITATION

Daily Inflow (Mgal)	Precip. (In.)
0.00	0.14
0.00	0.26
0.02	0.10
0.00	0.35
0.00	0.22
0.04	0.21
0.04	0.31
0.04	0.37
0.12	0.50
0.40	0.68
0.60	0.92
0.03	0.52
0.03	0.15
0.47	0.85
0.47	1.11
0.45	0.24

Regression Output:

Constant		-0.075
Std Err of Y Est		0.140
R Squared		0.621
No. of Observations		16.000
Degrees of Freedom		14.000
X Coefficient(s)	0.565	
Std Err of Coef.	0.118	

Notes: Dates of negative inflow have been deleted.
Dates with missing data have been deleted or interpolated.